THERMAL DISTORTION ANALYSIS OF A WF/PC QEH ENTRANCE MIRROR

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ABSTRACT

This paper describes the use of MSC/NASTRAN in determining the temperature distribution and subsequent surface distortion of the Wide Field/Planetary Camera (WF/PC) Quantum Efficiency Hysteresis (QEH) light pipe entrance mirror. Temperature variations due to electrical base heaters, solar radiation and radiative heat loss were calculated for various on-orbit thermal loading conditions. Mirror deformations were then found by imposing these temperatures as temperature loads in a structural analysis. Use of an RBE3 generated least-squares best fit reference plane to measure surface distortion and pointing error along with experiences in using radiative heat transfer are also discussed.

INTRODUCTION

Launch of the NASA Hubble Space Telescope (HST), currently scheduled for 1989, is expected to provide astronomers with a quantum jump in our knowledge of the universe. Viewing the cosmos from its 600-kilometer-high orbit outside of Earth's distorting atmosphere, HST will produce imagery of galaxies, star systems and our own Solar System with unprecedented clarity.

Five instruments, each located behind the telescope's primary mirror, will be used to obtain pictures and other scientific data. The primary imaging instrument is the Wide Field/Planetary Camera (WF/PC), see Figure 1. It consists of a complex arrangement of mirrors which split the field of view into four portions, each of which is focused onto a charged-coupled device (CCD). Each CCD consists of an 800 x 800 array of picture elements (pixels). Images will be received on Earth by transmitting the light intensities of each pixel to a ground station for assembly into complete pictures [1].

Current WF/PC CCD's unfortunately degrade over time due to a phenomenon known as Quantum Efficiency Hysteresis (QEH). Flooding with ultraviolet (UV) light, however, can restore their original performance. The QEH light pipe, see Figure 2, was added to periodically channel UV rich sunlight into the WF/PC optics, illuminating the CCD's. Since the time required for this process depends on the UV intensity, an efficient light pipe is desirable. Thermal/Vacuum testing using a solar simulator lamp has allowed characterization and adjustment of all light pipe optics except the external entrance mirror (M1).

The M1 mirror and its support bracket, see Figure 3, are constructed from integrally machined 6061-T651 aluminum alloy and connected at three points through spherical washer sets. The bracket attaches to an adaptor block which is heated to drive off surface contamination prior to pointing at the sun. All are mounted outside the HST aft shroud, exposed to space, and protected by only a multi-layered insulation (MLI) covered sheet aluminum hood. Temperature gradients resulting from adaptor block heaters, solar radiation and radiative heat loss will induce some mirror deformation. Concern over this distortion degrading optical performance was raised since all QEH light pipe testing required removal of the M1 mirror. A thermal analysis, including radiative heat transfer, was therefore performed to obtain temperature distributions, along with a structural analysis, using these temperatures as thermal loads, to determine mirror distortion.

COMBINED THERMAL AND STRUCTURAL ANALYSIS MODEL

An MSC/NASTRAN [2] finite element model was constructed of the M1 mirror assembly and its surrounding thermal environment. It consisted of both structural and heat transfer elements representing the mirror and its thermal boundaries, respectively. One model, with only minor changes, was therefore used for both the thermal and structural analysis.

The mirror portion consisted of eight-noded HEXA solid elements for the reflective surface allowing through-the-thickness temperature gradients. QUAD4 plate elements were also used for the ribs and support flange, see Figure 4. The support bracket was modeled using both plate and BAR elements. The MLI hood consisted of plate elements only, see Figure 5. MAT4 data cards provided heat conduction properties for each material. ELAS2 scalar elements were used to model the contact conductance of each bolted joint. HBDY [3] heat boundary elements were overlaid on the surfaces of radiating structural elements to model radiation exchange effects. The remainder of the model consisted of these same boundary elements used to represent those portions of the adaptor block, aft shroud and space visible to the mirror assembly, see Figure 6.

Only the mirror and support bracket structural elements were retained for the distortion analysis. ELAS2 elements were replaced by stiff BAR elements to provide a relatively rigid connection capable of thermal expansion. A similar arrangement was also used for the adaptor block. Surface distortion and pointing error were obtained using an RBE3 rigid element connected to a uniform distribution of equally weighted independent grid points on the mirror's surface. Displacement of the dependent reference grid represents the motion of a rigidly connected body which produces a least-squares best fit to the actual motion of the independent grid points. A reference plane was therefore constructed by connecting additional grid points, coincident to the surface nodes, back to the reference grid with an RBE2 rigid element. MPC constraint equations were then used to get distortion as the difference in displacements between coincident grids in the direction normal to the mirror's surface. Pointing error was given directly by the motion of the reference grid.

THERMAL DISTORTION ANALYSIS OF THE M1 MIRROR

Use of nonlinear steady-state heat transfer (SOL 74) with radiation heat exchange first required the calculation of the RADMTX geometric view factor matrix (area x view factor). An ideal matrix is symmetrical with zeros down the diagonal; i.e., an element cannot see itself. If a total view factor is less than unity, energy is being lost to space. Greater than one means that an element sees more than one hemisphere. Including the view of space with heat boundary elements provided a means of checking view factor accuracy by ensuring that the total for each element should equal to one. Where necessary, adjustments were made by taking the area x (1 - total view factor) and entering this value in the appropriate position on the matrix diagonal thereby forcing the new view factor total to unity. MSC/NASTRAN automatically does this for view factors greater than one and will flag each negative diagonal with a warning message [4]. The same can be done for view factors totaling less than one by setting SYSTEM(87) = 3 on the NASTRAN card to modify the internally computed radiation matrix. Using a DMAP Alter to exit after the VIEW module allowed examination of the results before proceeding with the rest of the solution sequence. Once satisfied, the matrix was output with THERMAL(PUNCH) = ALL and used in all subsequent thermal runs.

The next step involved a thermal analysis using the above exchange coefficients. Equilibrium temperatures were calculated for the on-orbit thermal conditions just prior to and after prolonged pointing at the sun. Each condition assumes that the adaptor block heaters maintain a temperature of 35°C, the radiator and aft shroud operate at -30°C, the MLI hood faces space, the structure was assembled at room temperature and the adaptor block is free to grow in-plane. Solar radiation illuminating the mirror's surface was applied only to the sun pointing case through QVECT data cards. The required initial temperature guess was overestimated to assure convergence of the iterative solution and is guaranteed if chosen greater than 80% of the correct temperature. Solution results were output as TEMP data card punch files for use in the structural analysis.

Linear static analysis (SOL 24) was finally employed to perform the distortion analysis using the calculated temperature distributions as thermal loads. Both surface deformation and overall pointing error were measured relative to the RBE3 generated reference plane. Surface distortion is given as the maximum peak-to-peak distance measured normal to the mirror's surface in waves of helium-neon laser light (1 wave = 25μin) and represents the absolute change from its room temperature condition. Pointing error is given as the maximum angular rotation of a reflected light ray and represents the relative change from the space to sun pointing conditions. Results for both are given in Table 1 along with contour plots of the deformed surface along both the major and minor mirror axes, see Figure 7 and 8 respectively [5].

CONCLUSIONS AND RECOMMENDATION

As can be seen from Figures 7 and 8, the mirror's surface assumes a "saddle" shape for both thermal conditions. Upon pointing toward the sun, the curvature reverses sign and increases in magnitude relative to the space pointing case. Neither condition exceeds six waves of surface distortion or one arcmin of pointing error defined as the upper limits for acceptable mirror performance. The M1 mirror, therefore, should perform adequately during the QEH flood with adaptor block heaters operating both before and during the entire cycle.

The most costly and time-consuming process of this solution involved the calculation of view factors for the radiative heat transfer analysis. This was complicated by the fact that parts of the model can block or "shade" other parts from radiative energy exchange. To obtain results at reasonable expense, it was found necessary to reduce the total number of heat boundary elements by violating the rule of one-to-one correspondence between surface and HBDY elements. Conduction, in effect, was used to smear the radiative boundary condition between structural elements without causing noticeable temperature or displacement discontinuities.

Finally, use of the RBE3 generated reference plane greatly simplified the task of determining surface distortion. This technique can provide a convenient means for separating any structural deformation into its rigid body and elastic components.

ACKNOWLEDGEMENTS

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Table 1. Thermal Distortion

Pointing Direction	Surface Distortion (waves)	Pointing Error (deg)
Space	0.59	0°- 0'- 0"
Sun	3.69	0°- 0'- 6.9"

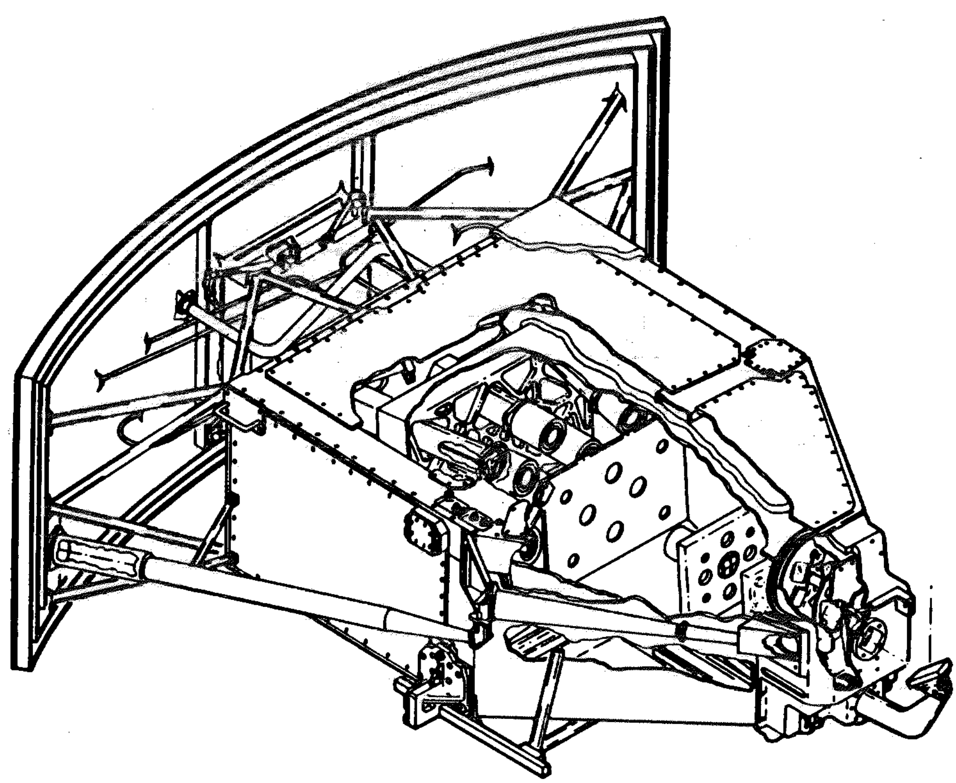

Figure 1. Wide Field/Planetary Camera

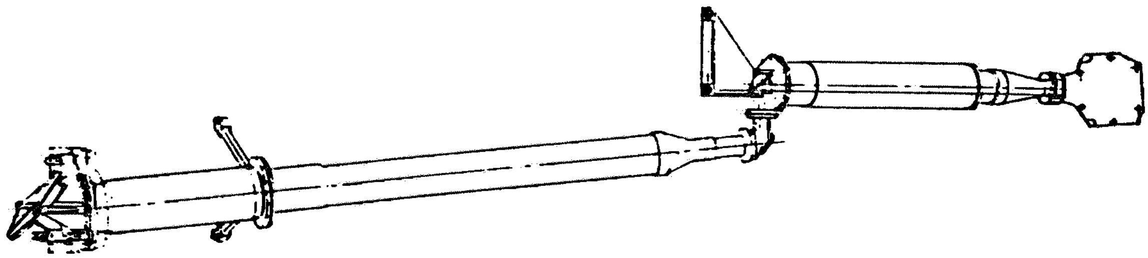

Figure 2. QEH Light Pipe

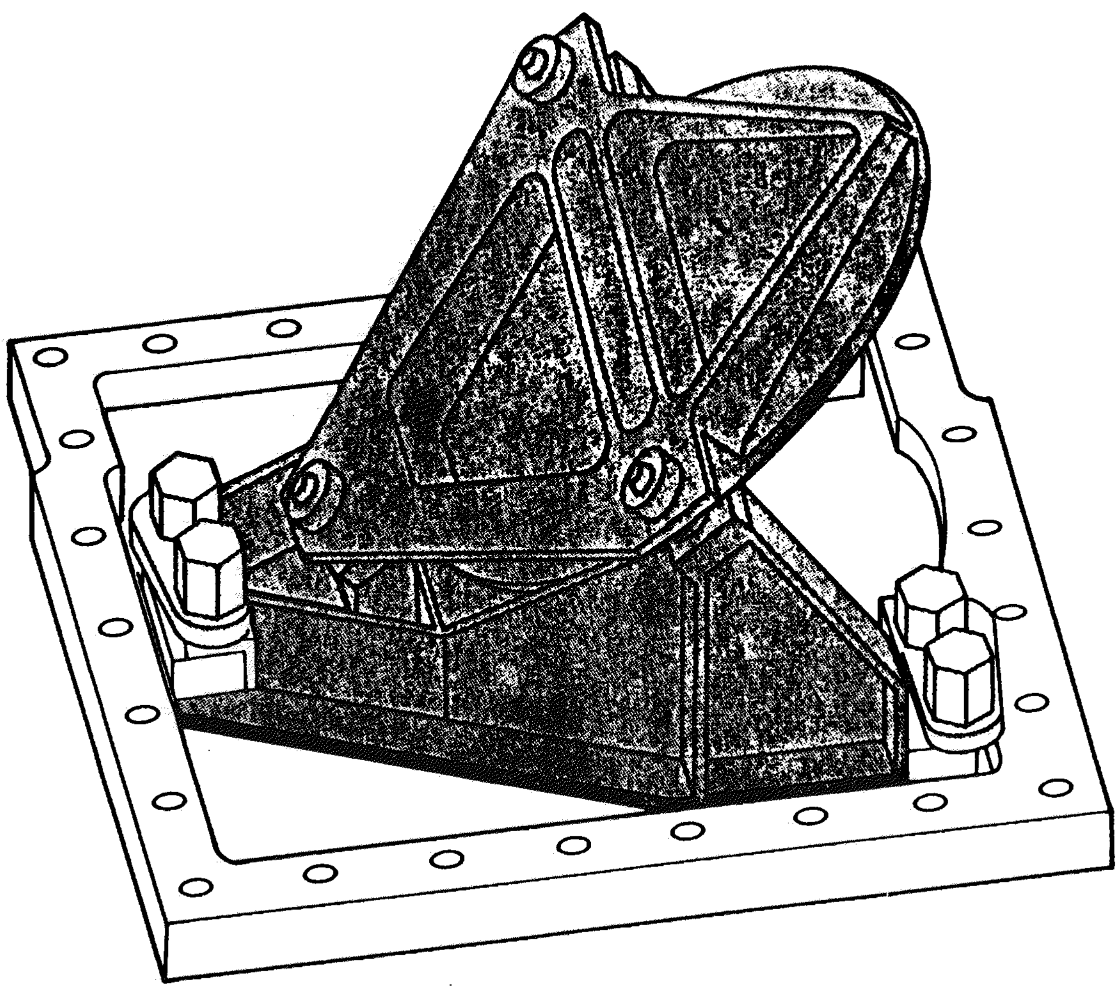

Figure 3. M1 Entrance Mirror

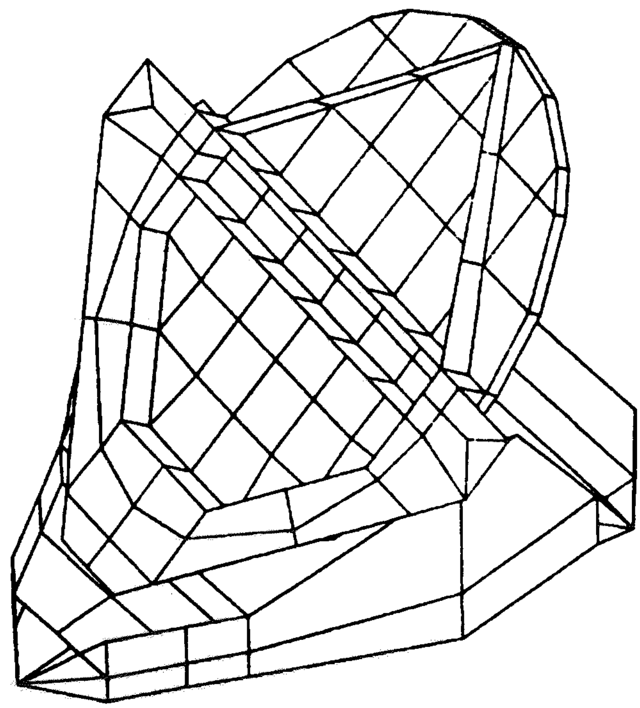

Figure 4. Finite Element Model of M1 Mirror Assembly

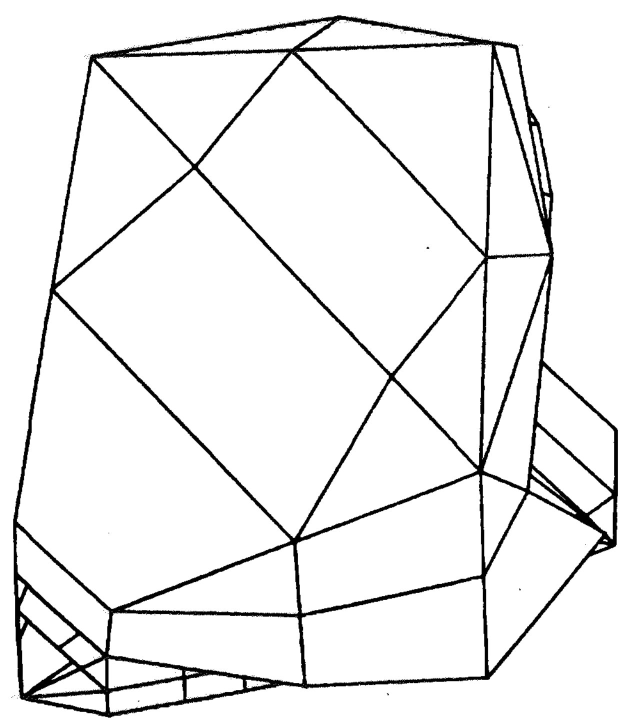

Figure 5. Finite Element Model of Mirror Assembly With Hood

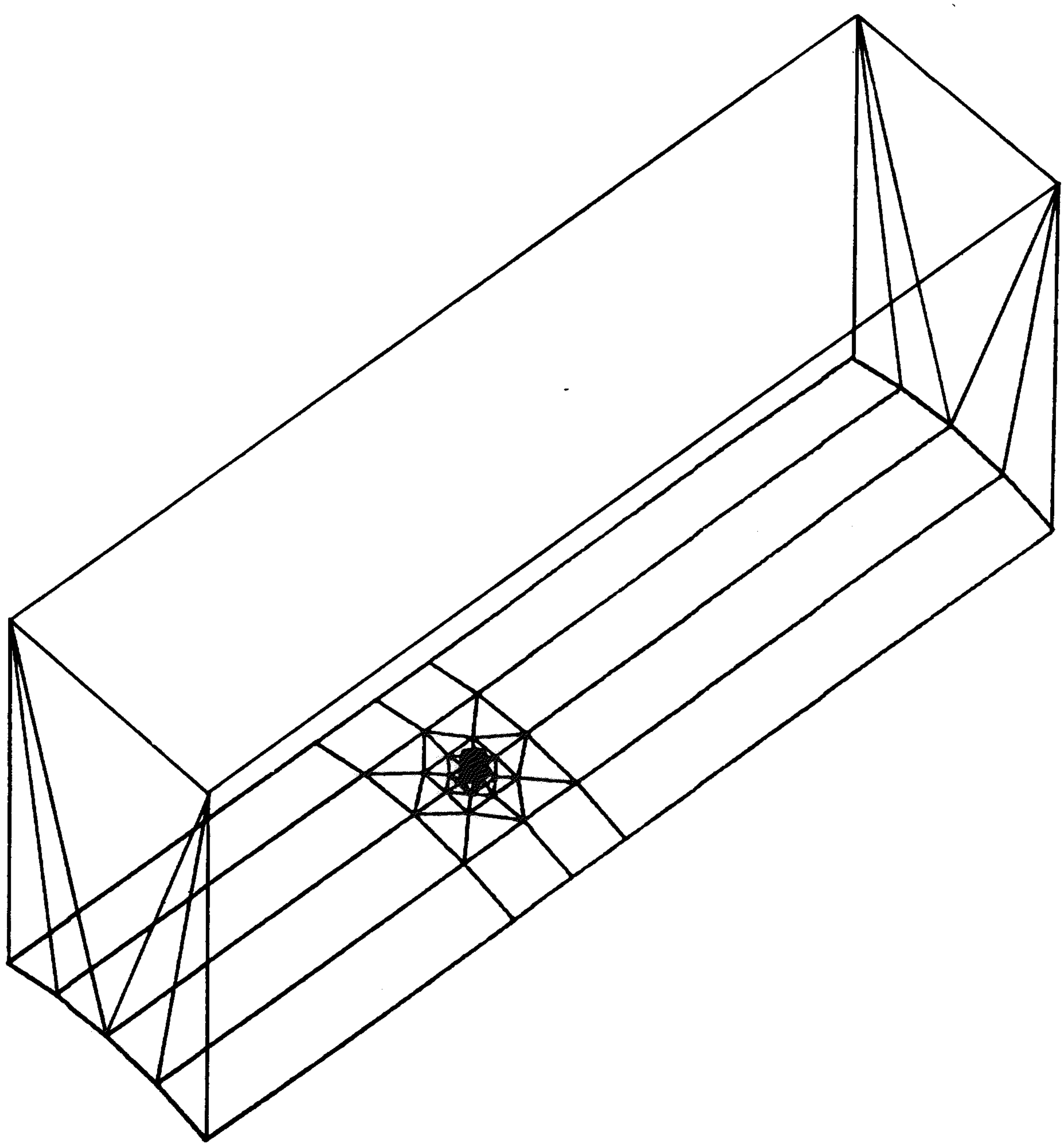

Figure 6. Radiation Exchange Boundary Elements

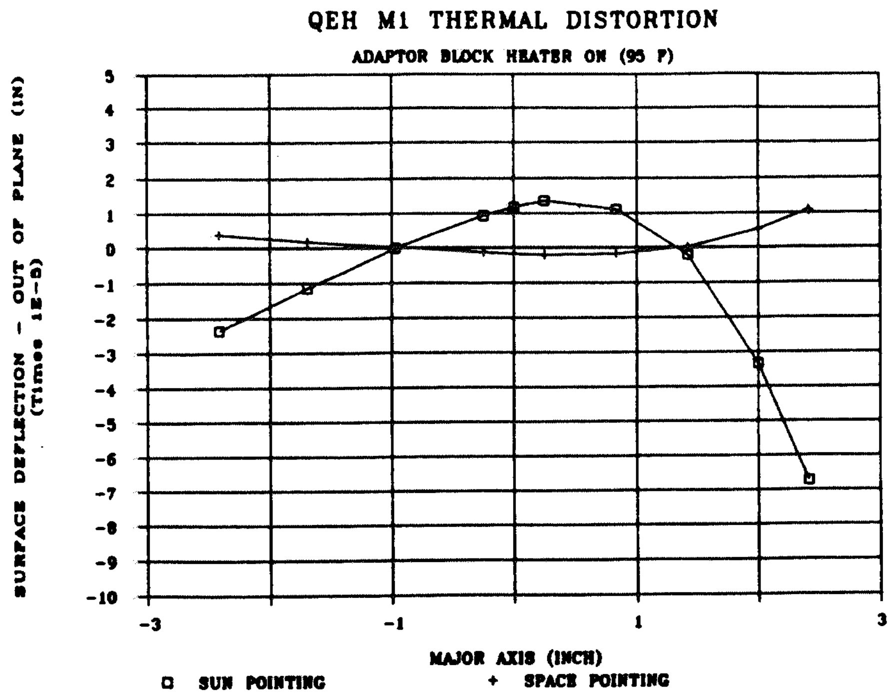

Figure 7. Major Axis Surface Deformation

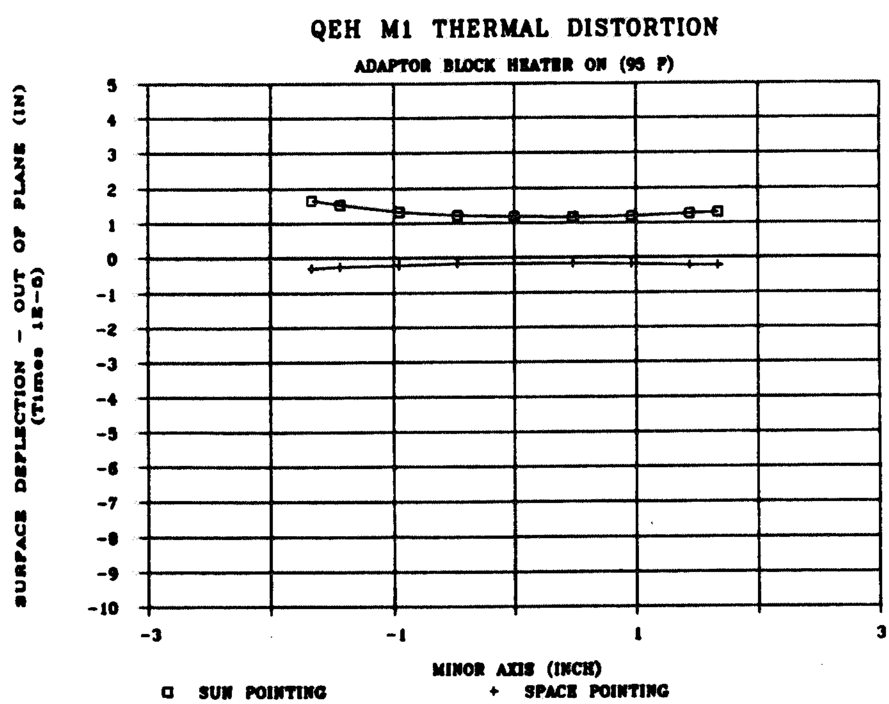

Figure 8. Minor Axis Surface Deformation